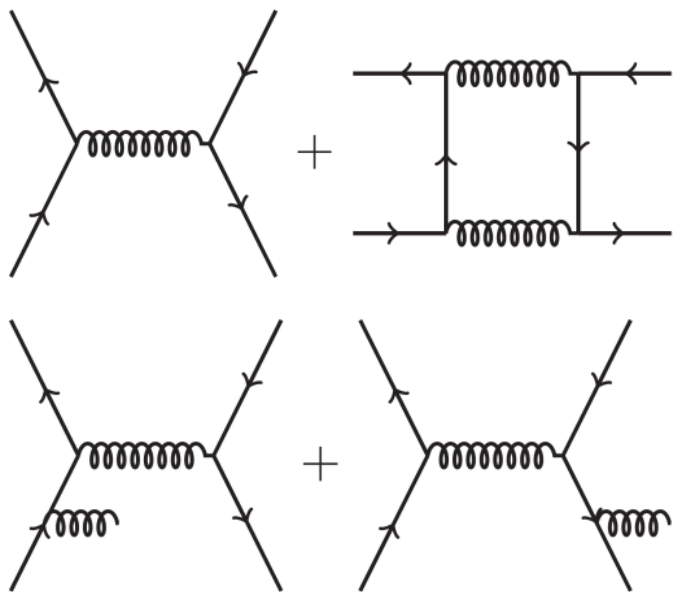


Top Quark Production Asymmetry at the Tevatron

Dan Amidei
University of Michigan

top A_{FB} in NLO QCD



- $C = -1 + C = +1 \rightarrow A_C$
- at Tevatron this is an A_{FB}

- measure in $\Delta y = y_t - y_{\bar{t}}$

$$A^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

- inclusive NLO prediction (QCD+EWK)

$$A_{\text{FB}} = (6.6 \pm 2.0 + 2.0?)\%$$

- measured

$$A_{\text{FB}} \sim (19 \pm 4)\%$$

- new work on SM calculation

- EWK, denominators
- t-tbar P_t , parton showers
- NNLO is coming

- many interesting NP models

- s-channel, t-channel

top Δy asymmetry in l+jets

- similar analyses

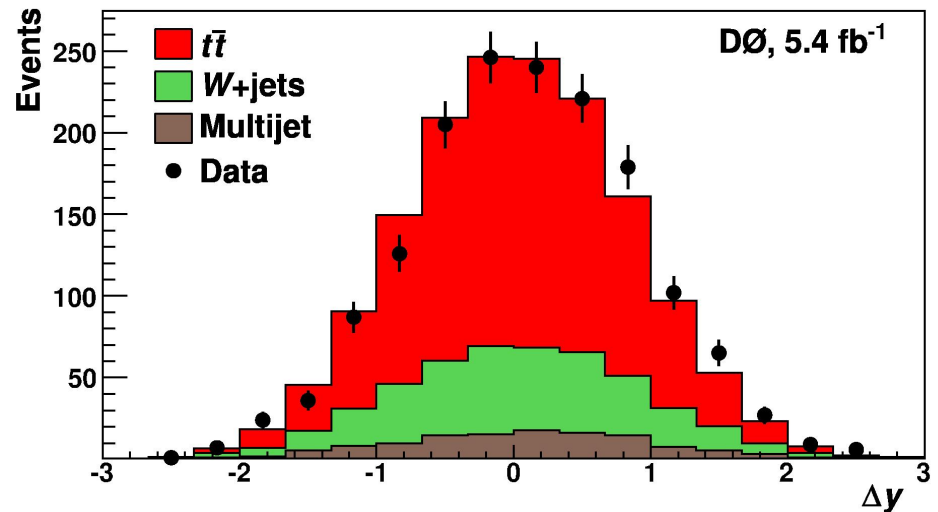
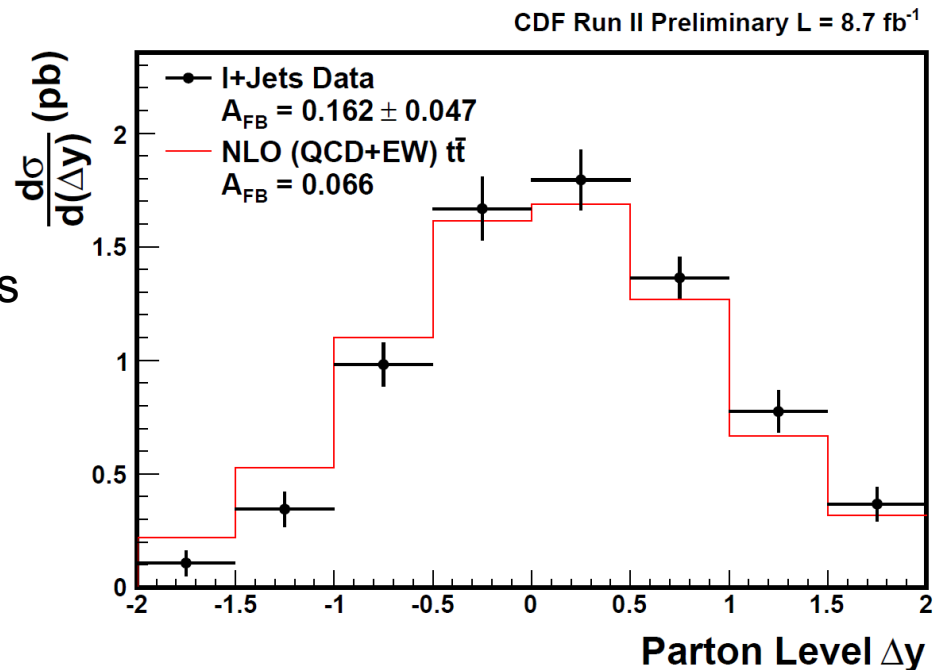
- subtract backgrounds
- kinematic reco of top 4-vectors
- SVD unfold

- CDF

- arXiv:1211.1003
- 9.4 fb^{-1} , 2653 evnts 530 bkg
- differential xsec in Δy
- $A_{\text{fb}} \text{ parton} = (16.2 \pm 4.7)\%$

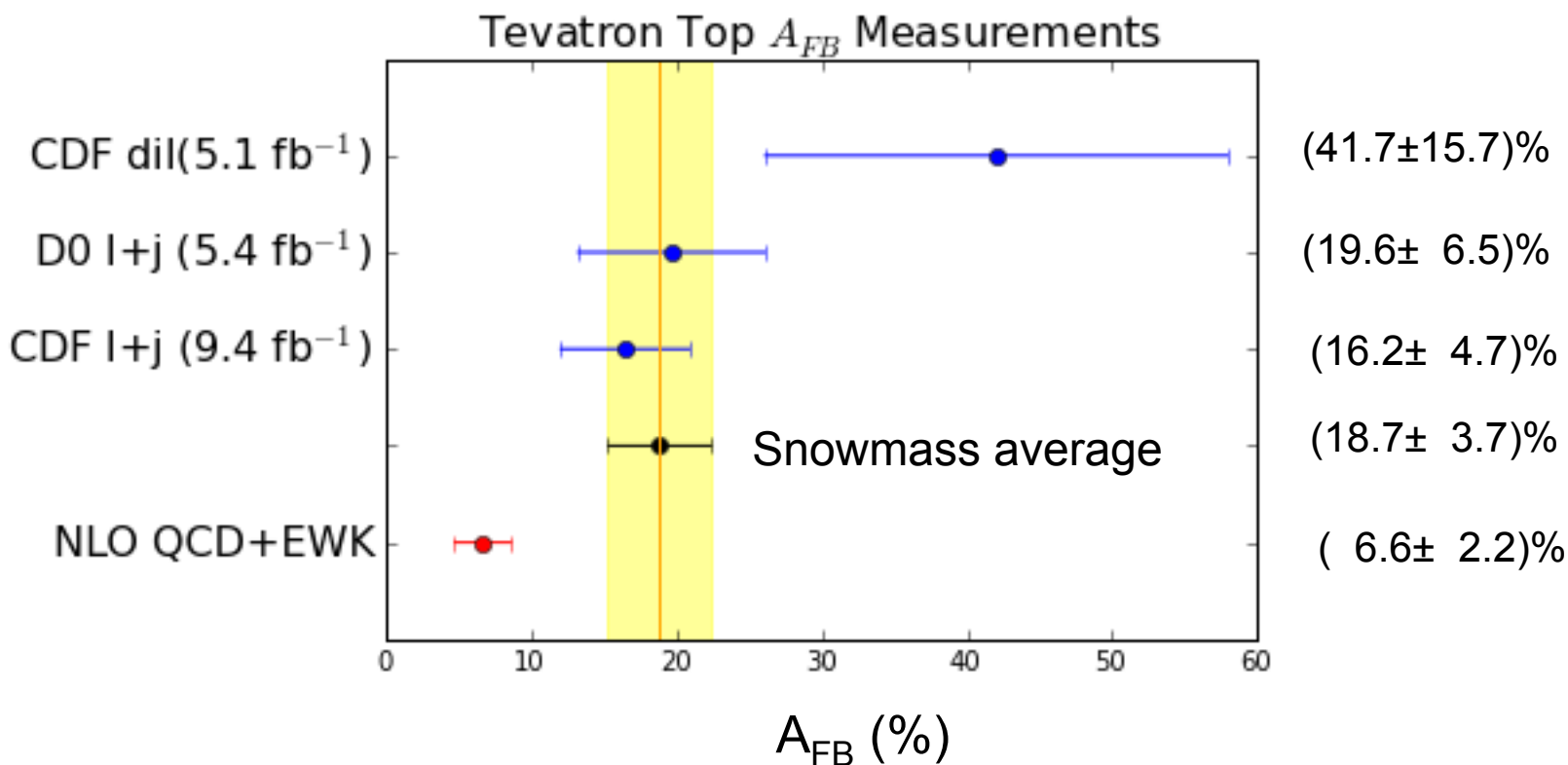
- D0

- PRD84, 112005 (2011)
- 5.4 fb^{-1} , 1581 evnts 455 bkg
- $A_{\text{fb}} \text{ parton} = (19.6 \pm 6.5)\%$



comparison of tevatron top Δy A_{FB} results Sept. 2012

- including private average
simple weighted, neglect correlations

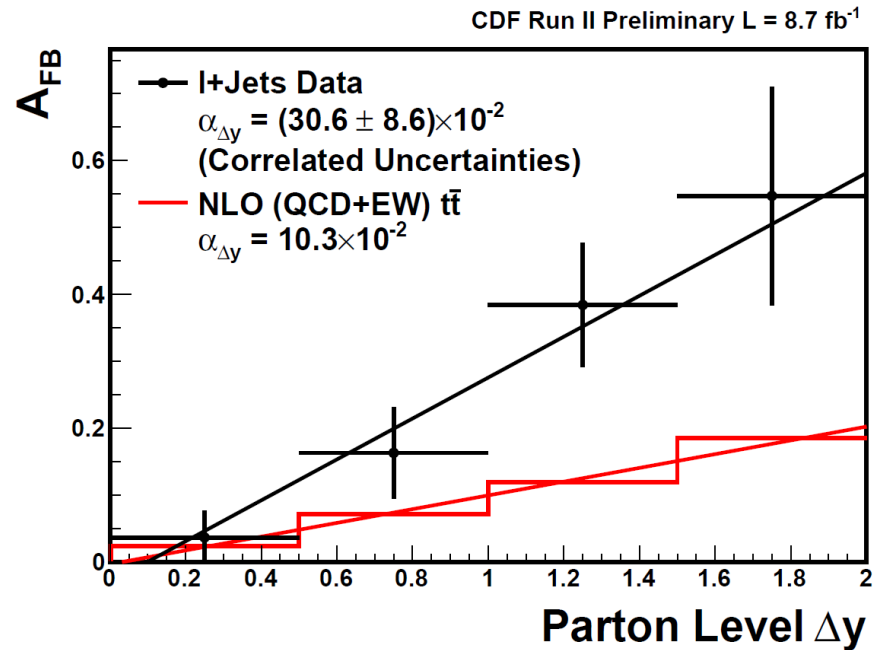


- expected precision w 9 fb⁻¹ for all measurements < 3%.

differentially

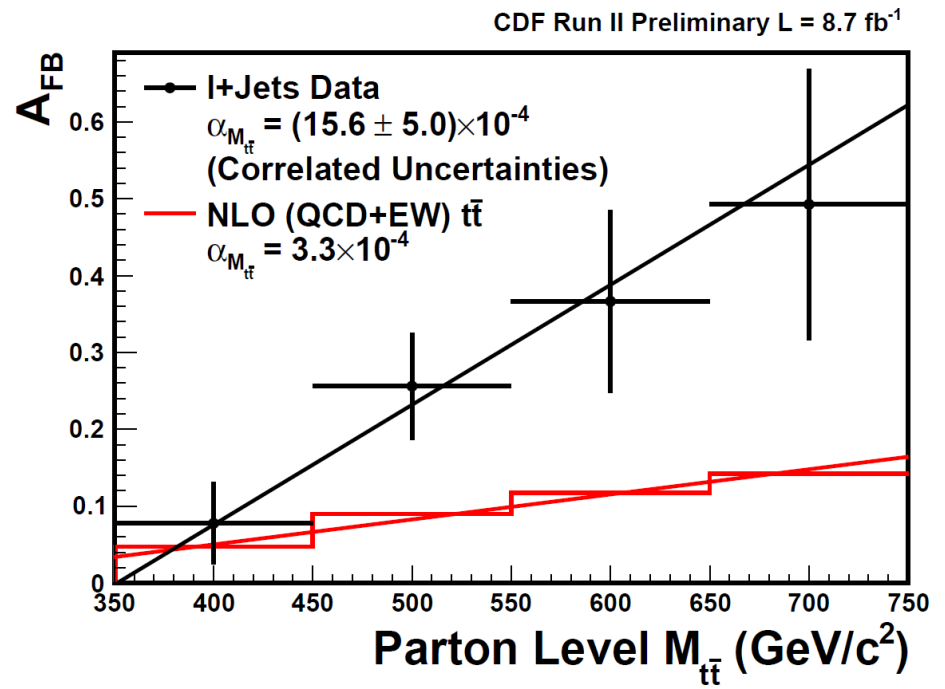
- rapidity dependence

- fit $\chi^2_{\text{p.d.f.}} = 1.0$
- slope $> 3\sigma$ from 0
- PE how often $\alpha_{\text{NLO}} \geq \alpha_{\text{data}}$
- use background sub data
- $p_{\text{NLO}} = 0.00892$



- mass dependence

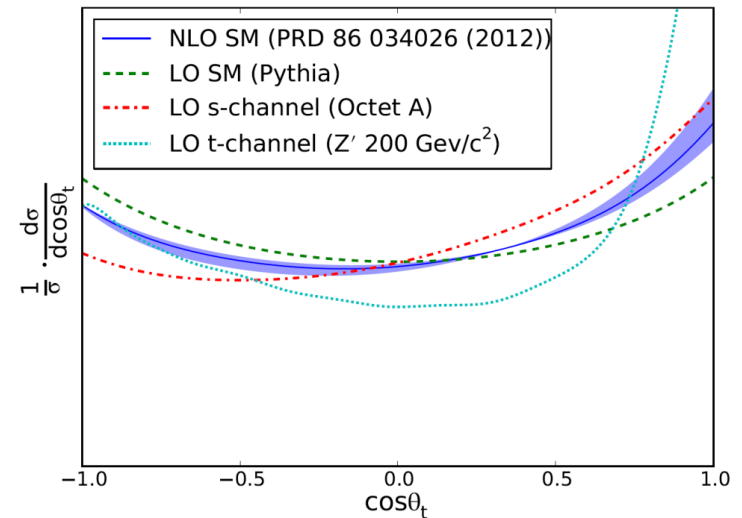
- slope is $> 3\sigma$ from 0
- fit $\chi^2_{\text{p.d.f.}} = 0.3$
- $p_{\text{NLO}} = 0.00646$



differential top cross-section in production angle $\cos\theta^*$

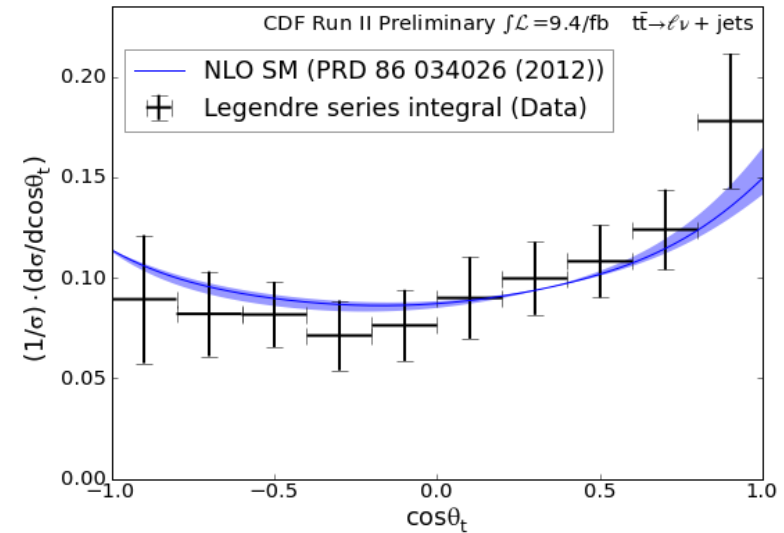
- full reconstruction in $t\bar{t}$ frame

- study production angle directly
- SM $\sim 1 + \cos^2\theta$
- NLO adds asymmetry
- s-channel models add $\cos\theta$ term
- t-channel leading term $1/(1-\cos\theta)$
- some benchmark models on right



- new CDF analysis in $l + \text{jets}$

- 9.4 fb⁻¹ 3864 evnts, 1026 bkg
- reconstruct $\cos(\theta^*)$
- decompose in 8 Legendre moments
- no binning, no regularization
- estimate moments response from MC
- invert response, multiply by bkg subtracted moments
- integrate series over 10 bins

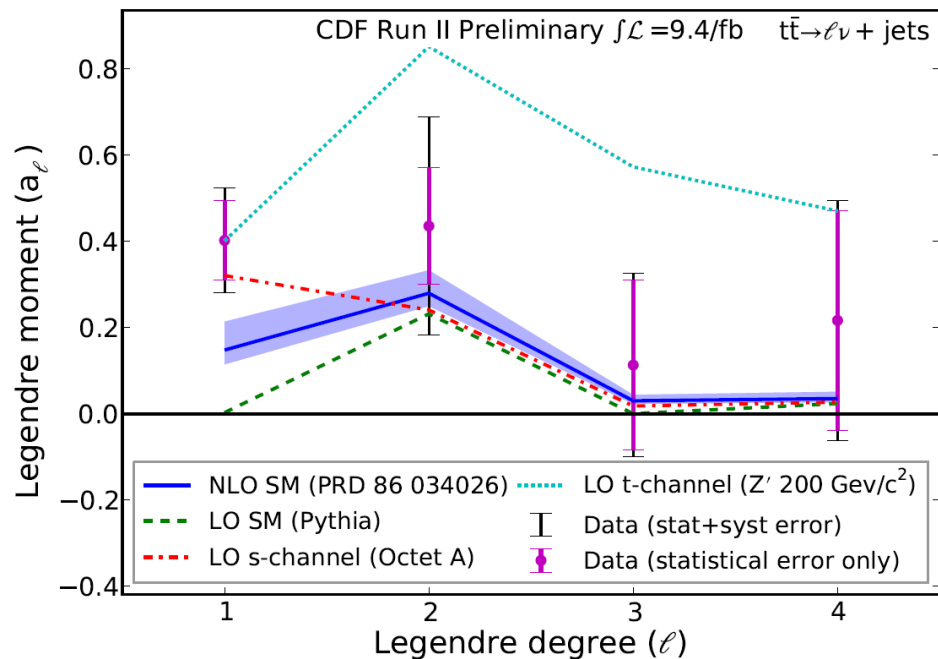


J. Wilson LaThuile, 2013

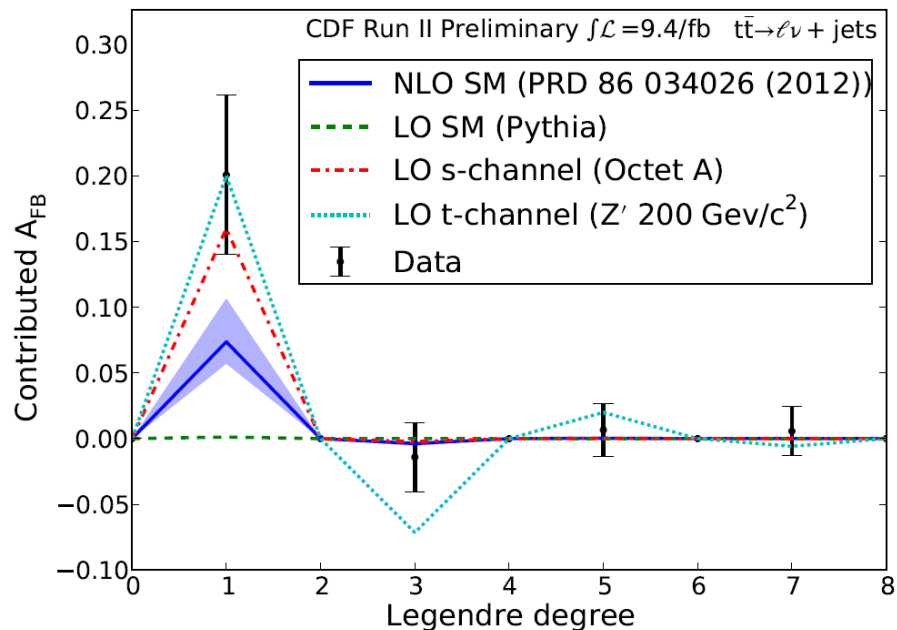
study the scattering angle directly

- moments

- SM agreement except $L = 1$
- $a_1 = 0.44 \pm 0.12$ measured
 0.15 ± 0.05 expected
- excess linear term in xsec
- benchmark Z' model is disfavored

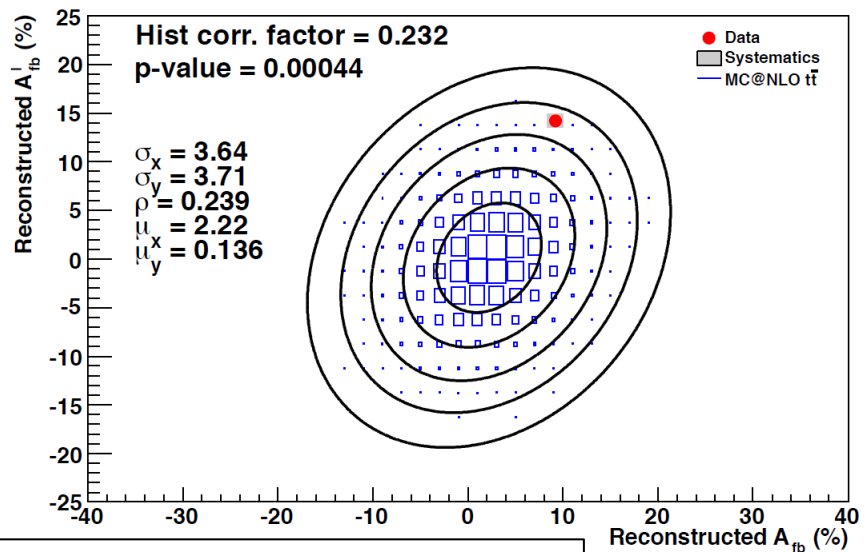
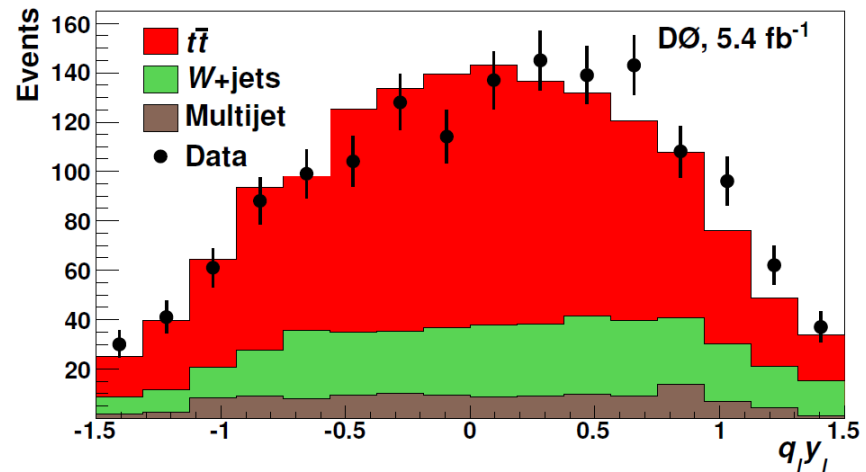


- contribution of moments to A_{fb}
 - independent asymmetries add!
 - A_{FB} is entirely due to linear term



single lepton in $l+jets$

- lepton
 - well measured
 - follows top quark
 - $A(q_{Tl})$ robust asymmetry probe
 - correlation with $A(\Delta y)$ sensitive to polarization
- pioneered by D0
 - PRD84, 112005 (2011)
 - 5.4 fb⁻¹, 1581 evnts 455 bkg
- data A_{fb}
 - $(14.2 \pm 3.8)\%$ obs
 - $(0.8 \pm 0.6)\%$ pred
- parton A_{fb}
 - $(15.2 \pm 4.0)\%$ obs
 - $(2.1 \pm 0.1)\%$ pred



R. Demina HCP Kyoto, 2012

D0 dilepton rapidity asymmetries

- arXiv:1207.0364
- 5.4 fb^{-1} , 2 OS leptons (M.ne.Z) + met + 2 jets + Ht
- 649 events bkg = 244 ± 18
- no tt reconstruction: it's the leptons

	Raw	Unfolded	Predicted	
A^ℓ	$2.9 \pm 6.1 \pm 0.9$	$2.5 \pm 7.1 \pm 1.4$	4.7 ± 0.1	A_C
$A_{\text{FB}}^{\ell^+}$	$4.5 \pm 6.1 \pm 1.1$	$4.1 \pm 6.8 \pm 1.1$	4.4 ± 0.2	+ charge leptons
$A_{\text{FB}}^{\ell^-}$	$-1.2 \pm 6.1 \pm 1.3$	$-8.4 \pm 7.4 \pm 2.4$	-5.0 ± 0.2	- charge leptons
A_{FB}^ℓ	$3.1 \pm 4.3 \pm 0.8$	$5.8 \pm 5.1 \pm 1.3$	4.7 ± 0.1	both charges (q.η)
$A^{\ell\ell}$	$3.3 \pm 6.0 \pm 1.1$	$5.3 \pm 7.9 \pm 2.9$	6.2 ± 0.2	Δy leptons
A_{CP}^ℓ	$1.8 \pm 4.3 \pm 1.0$	$-1.8 \pm 5.1 \pm 1.6$	-0.3 ± 0.1	CP violating

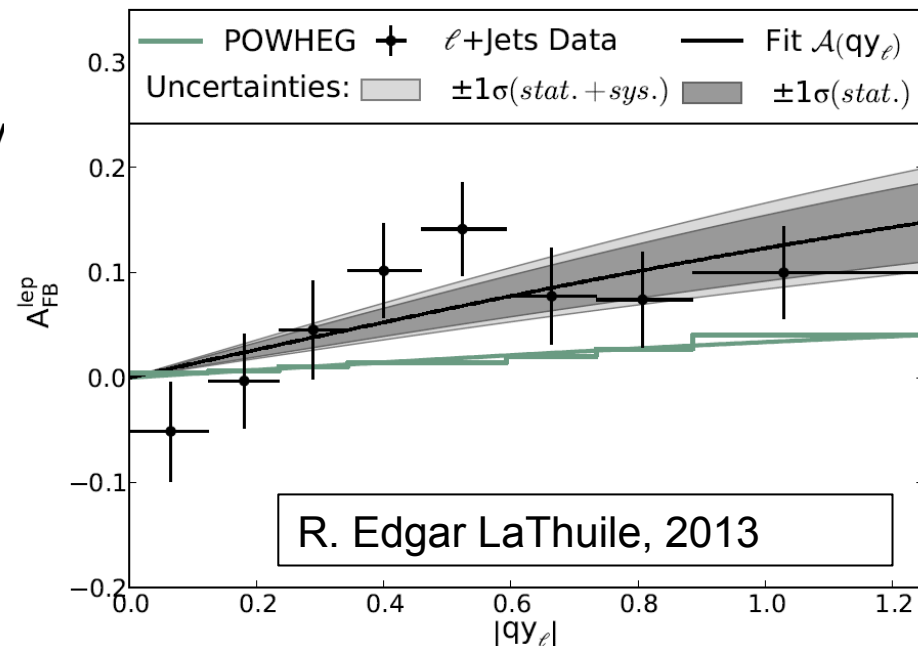
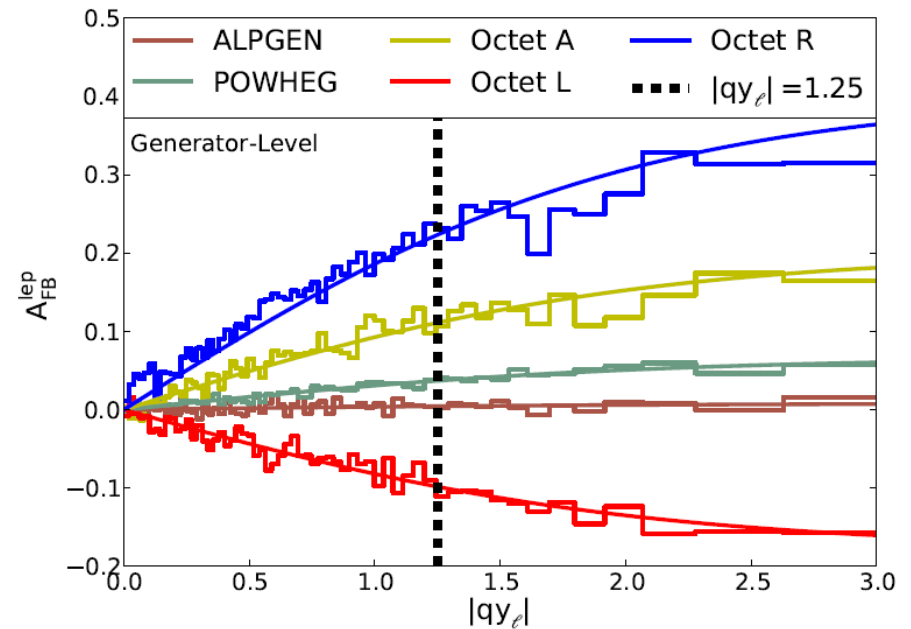
inclusive lepton asymmetry at CDF

- study $q \cdot y_l$
 - “asymmetric part” $A_l(qy_l)$
 - symmetric part is model independent
- ansatz $\mathcal{A}(qy_l) = a \tanh \left[\frac{1}{2} qy_l \right]$
 - well fit in benchmark models
 - OctetA heavy, unpolarized
 - OctetsLR light, polarized
 - extrapolates into forward region
- technique
 - integrate with symmetric part
 - gets full distribution + total asymmetry
 - works well in benchmarks

measurement

- 9.4 fb^{-1} 3864 evnts, 1026 bkg

$$A = 0.094 \pm 0.024^{+0.022}_{-0.018}$$



R. Edgar LaThuile, 2013

combined lepton asymmetry

- D0 combination

- $A_{FB}^l \text{ DIL} = (5.8 \pm 5.3) \% \quad \text{pred } (4.7 \pm 0.1)\%$
- $A_{FB}^l \text{ l+jets} = (15.2 \pm 4.0)\% \quad \text{pred } (2.1 \pm 0.1)\%$
- D0 combination $A_{FB}^l = (11.8 \pm 3.2)\%$

- CDF l+jets

- $A_{FB}^l \text{ l+jets} = (9.4 \pm 3.1) \% \quad \text{pred } (3.8 \pm 0.3)\%$

- informal combination

- $A_{FB}^l = (10.5 \pm 2.2)\% \quad \text{exceeds SM predictions by 3-4 } \sigma$

- what do we expect for SM decays with measured $A(\Delta y)$?

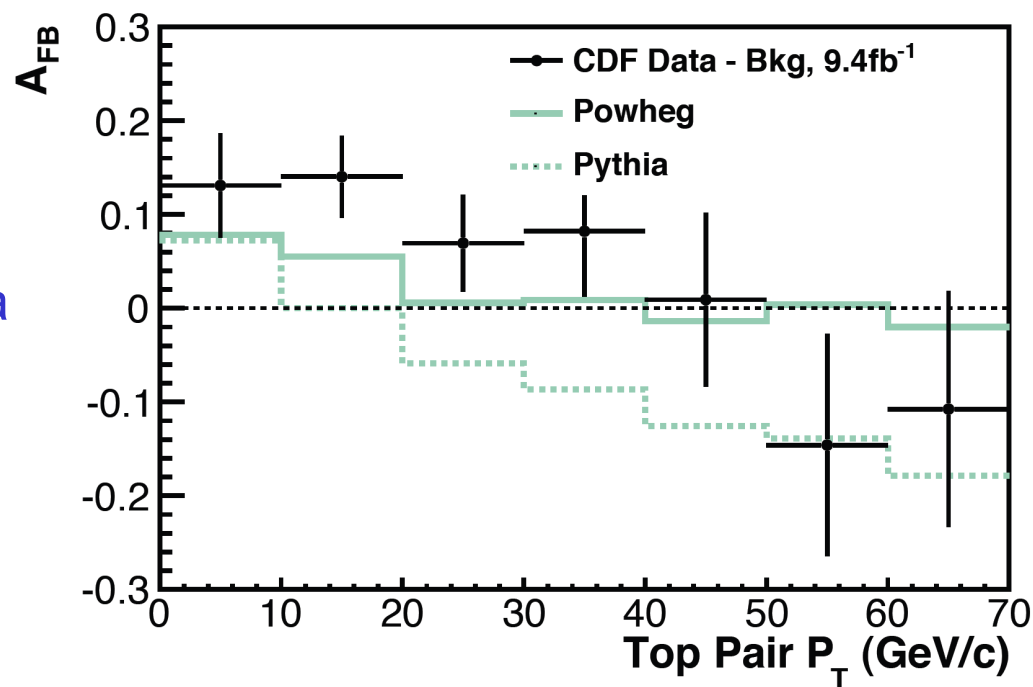
- crude measure

$$\left. \frac{A_{FB}^l}{A_{FB}^{\Delta y}} \right|_{\text{powheg}} \times A_{FB}^{\Delta y} \Big|_{\text{data}} = 0.46 \times (18.7 \pm 3.7) = 8.6 \pm 1.7$$

- would be interesting to have a real prediction

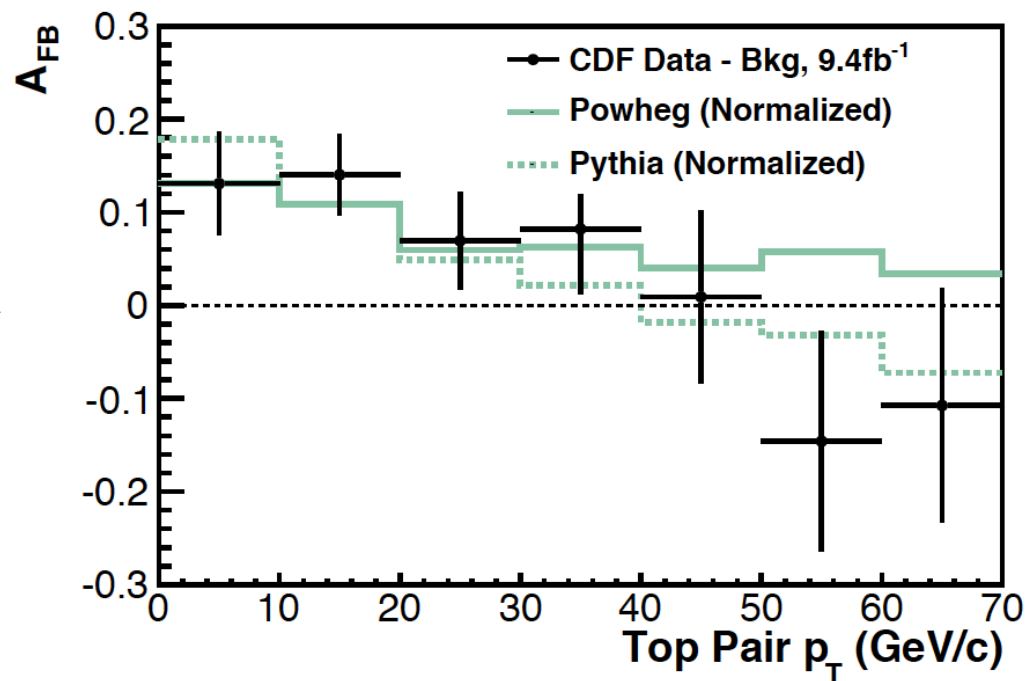
$p_t(t\bar{t})$ dependence of the asymmetry at CDF

- examine at obs bkg-sub level
 - pythia and powheg follow expected trend
 - CDF 8.7 fb⁻¹ l+jets
 - data above predictions
- normalize predictions to the data
 - independent asymmetries add!
 - scale each bin by inclusive A_{fb}
- good agreement with either Powheg and Pythia
- excess asymmetry is P_t independent?



p_t ($t\bar{t}$) dependence of the asymmetry at CDF

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summary

- inclusive asymmetry in agreement CDF+D0
 - informal combo $A_{FB}^{tt} \sim (18.7 \pm 3.7)\%$
 - eventual combined $\delta A_{FB} \sim 3.0\%$
- linear M_{tt} and Δy dependence of A_{fb} in tt system (CDF)
 - slopes 3σ from zero and 2σ larger than NLO prediction
- $d\sigma/d\cos(\theta^*)$ (CDF)
 - decompose in legendre moments
 - excess linear term
- measured 2-3 σ asymmetry in the lepton alone (D0 +CDF)
 - slightly high for measured $A(\Delta y)$?
- $p_t(tt)$ dependence agrees with Poweg/Pythia + p_t independent offset
- some tension between D0 dileptons and everything else
- picture still incomplete, much work still to do

additional material

lepton asymmetry method

$$\mathcal{S}(qy_l) = \frac{N(qy_l) + N(-qy_l)}{2}$$

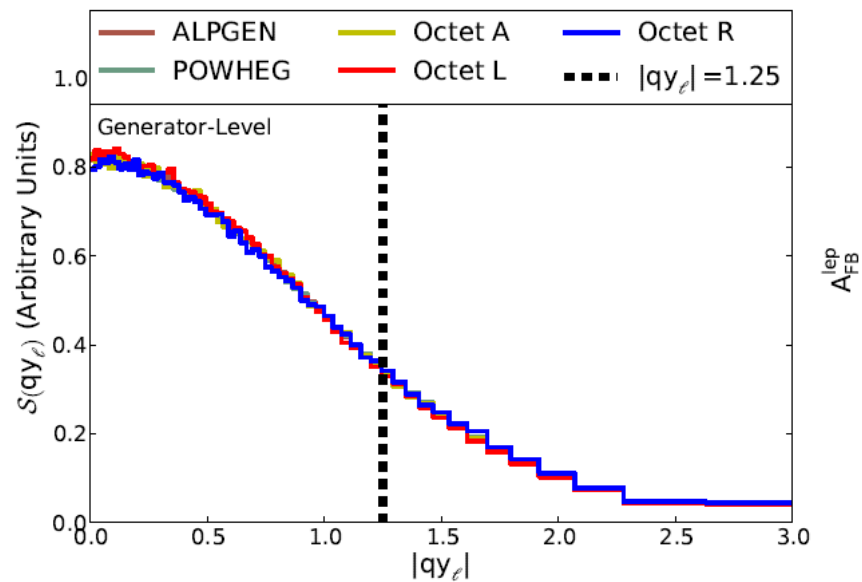
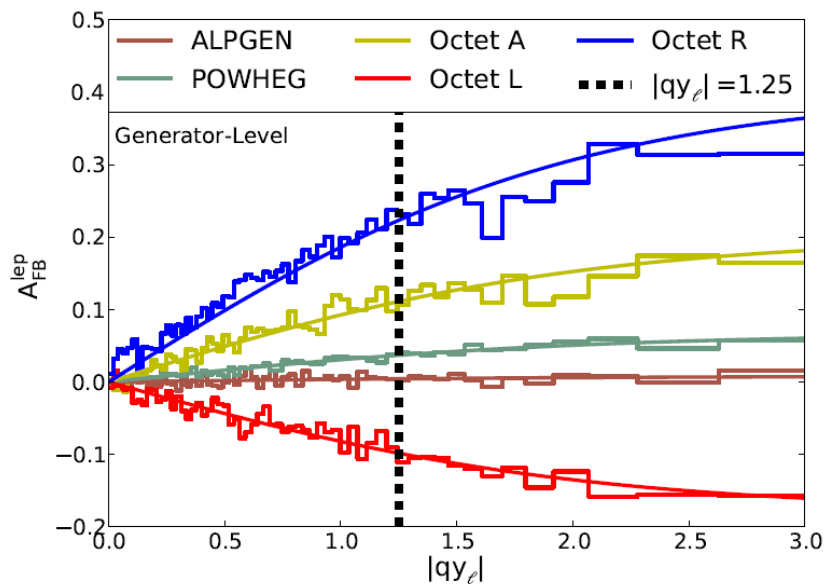
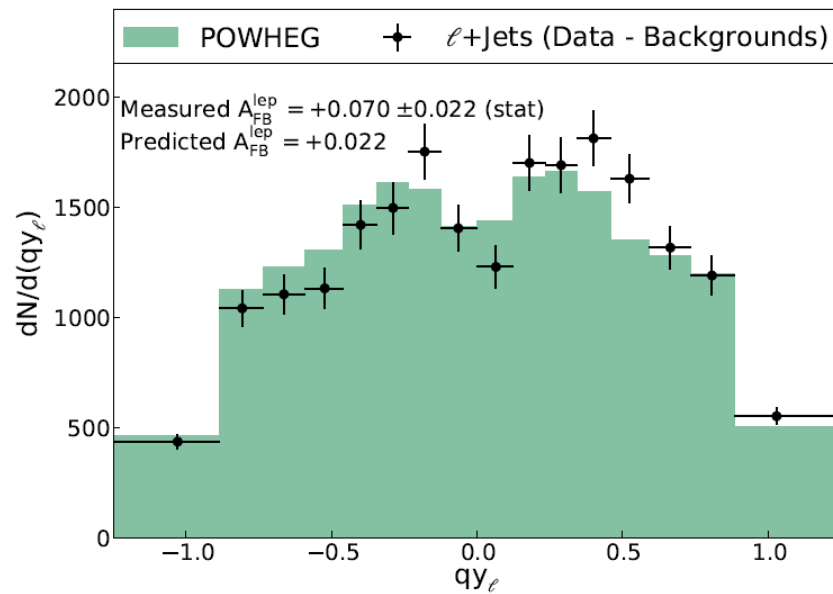
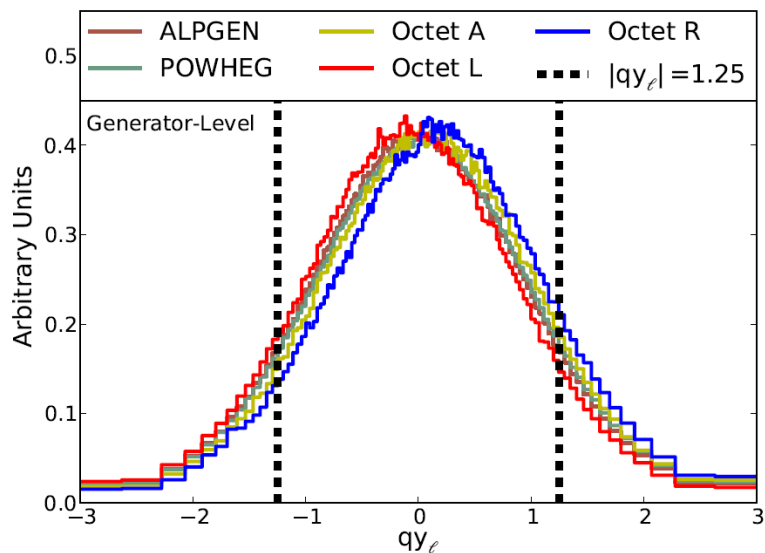
$$\mathcal{A}(qy_l) = \frac{N(qy_l) - N(-qy_l)}{N(qy_l) + N(-qy_l)}$$

$$N(qy_l > 0) = \int_0^{\infty} dqy_l [\mathcal{S}(qy_l) \times (1 + \mathcal{A}(qy_l))]$$

$$N(qy_l < 0) = \int_0^{\infty} dqy_l [\mathcal{S}(qy_l) \times (1 - \mathcal{A}(qy_l))]$$

$$\begin{aligned} A_{FB}^{lep} &= \frac{N(qy_l > 0) - N(qy_l < 0)}{N(qy_l > 0) + N(qy_l < 0)} \\ &= \frac{\int_0^{\infty} dqy_l [\mathcal{A}(qy_l) \times \mathcal{S}(qy_l)]}{\int_0^{\infty} dqy_l \mathcal{S}(qy_l)} \end{aligned}$$

lepton asymmetry method



lepton asymmetries

- lepton follows top
 - independent of asymmetry mechanism if $P=0$
- reconstructed lepton η is systematically unencumbered
- “bias free” asymmetry indicator

single lepton

$$A_{FB}^{l^\pm} = \frac{N_{l^\pm}(\eta > 0) - N_{l^\pm}(\eta < 0)}{N_{l^\pm}(\eta > 0) + N_{l^\pm}(\eta < 0)}$$

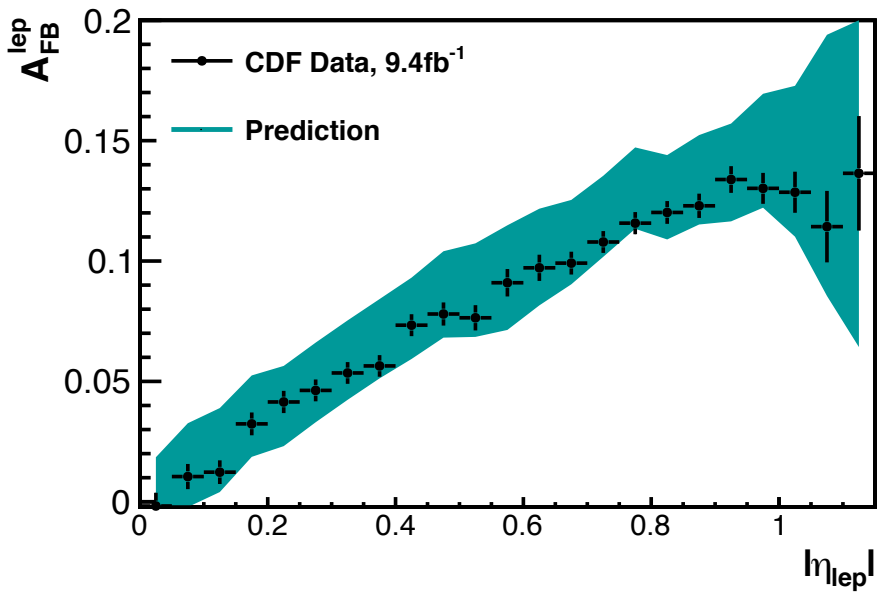
$$A_{FB}^l = \frac{N_l(Q \cdot \eta > 0) - N_l(Q \cdot \eta < 0)}{N_l(Q \cdot \eta > 0) + N_l(Q \cdot \eta < 0)}$$

two lepton

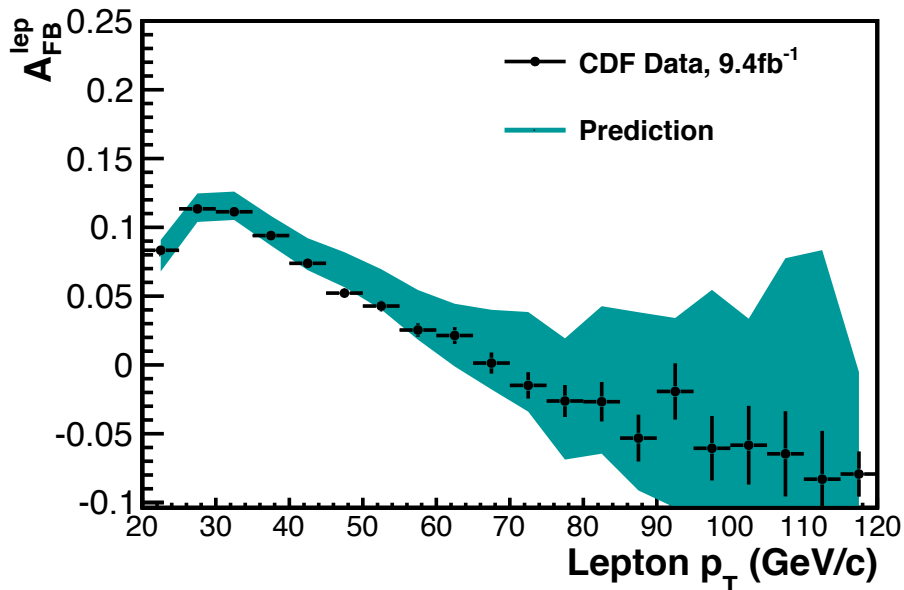
$$A^{ll} = \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)}$$

$$A_{CP}^l = \frac{N_{l^+}(\Delta\eta > 0) - N_{l^-}(\Delta\eta < 0)}{N_{l^+}(\Delta\eta > 0) + N_{l^-}(\Delta\eta < 0)}$$

lepton A_{FB}^{lep} performance in the W+1 jet sample (CDF)



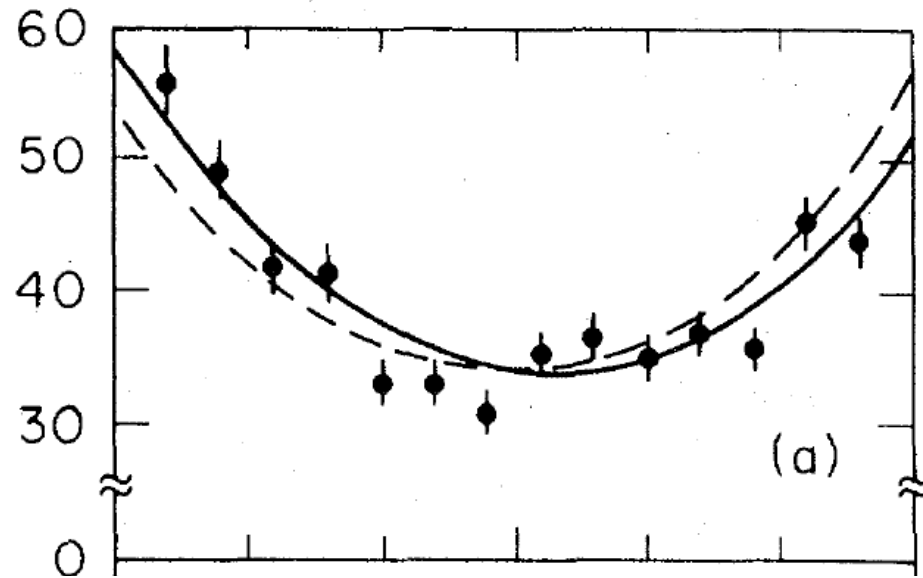
	$ \eta_{\text{lep}} < 0.75$	$ \eta_{\text{lep}} \geq 0.75$
Observed Data	0.059 ± 0.001	0.124 ± 0.002
SM Prediction	0.063 ± 0.005	0.134 ± 0.008
Data Minus Prediction	-0.004 ± 0.005	-0.010 ± 0.008



	$p_T < 60 \text{ GeV}/c$	$p_T \geq 60 \text{ GeV}/c$
Observed Data	0.083 ± 0.001	-0.009 ± 0.004
SM Prediction	0.089 ± 0.004	-0.001 ± 0.013
Data Minus Prediction	-0.006 ± 0.004	-0.008 ± 0.014

Historical perspective

e^+e^- 29 GeV



Z discovered below pole, 1983